USE OF RECYCLED AND WASTE FIBERS IN ASPHALT CONCRETE

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Abstract

A significant problem associated with asphalt concrete mixtures is the lack of durability resulting from an inadequate asphalt cement content. Additional asphalt cement added to increase durability results in flushing, bleeding and a significant loss in stability. Fibers have been used in stone matrix asphalt and open-graded friction course pavements successfully throughout Europe to allow higher asphalt cement contents for many years. The presence of recycled and waste fibers in mixtures offer the potential of durable, longer lasting roads.

This paper summarizes the findings of two independent studies. One investigation studied four fiber types in an asphalt concrete with a polymer modified asphalt cement to measure the effectiveness of commercial and recycled/waste fibers. All four fibers; commercial cellulose and polyester and waste nylon and ground carpet, were added to an asphalt concrete mixture at the same proportions. Stabilities, air voids and "voids in the mineral aggregate" (VMA) were measured to evaluate mixture properties as affected by the different fiber types. Stripping resistance tests, Resilient Modulus and indirect tensile stress tests were conducted according to the Asphalt-Aggregate Mixture Analysis System (AAMAS) to measure performance of the fiber mixtures. A comparison study was conducted on mixtures compacted to densities simulating the densities achieved at construction. Indirect Tensile Strengths and Resilient Modulus were measured.

Evaluation of overall performances of the different fiber types suggests all fibers can be used in asphalt concrete mixtures. The waste nylon fibers and the ground carpet showed a higher VMA and an increase in stability versus the commercial fibers. All of the fibers were effective in increasing the asphalt cement content by 0.3 to 0.4 percent.

BACKGROUND

Inadequate asphalt cement contents in asphalt concrete mixes have been labelled as a significant problem for asphalt concrete mixtures, due to the resulting lack of durability in today's pavement systems. An initial solution often involves changing the aggregate gradation to allow for an increase of the asphalt cement content or simply increasing the asphalt content. Often this results in flushing and bleeding pavements and significant increases in permanent deformation of the pavement. Most of this problem can be alleviated with proper aggregate gradation to provide adequate space for the asphalt cement. However, the optimal amount of asphalt cement resulting from these changes in gradation may not be enough to ensure performance of dense graded mixtures. A different approach to reducing this problem is to add fibers to the mixture to stabilize the asphalt cement, allowing for higher asphalt cement percentages. Fiber stabilization of stone matrix asphalt and open graded friction courses has been successfully used throughout Europe[1]. The use of fibers in dense graded mixtures is relatively new technology and has not been widely used. Fiber enhancement of dense graded mixes may offer the potential of durable, longer lasting roads without an increased risk of permanent deformation.

Earlier research suggests that the addition of fibers will improve binder-mixture properties by increasing the amount of asphalt cement, which in turn improved durability characteristics of the mixture. Several man-made, commercially available fibers exist that can be purchased for use in asphalt concrete mixtures. The asphalt industry has recently received a mandate to use waste and recycled material in asphalt concrete pavement construction. This investigation addresses the issue of performance of fiber asphalt concrete and how waste and recycled fibers compare to commercially available fibers. The waste/recycled fibers are by-products that must be used in an environmentally safe and effective manner or they will be disposed in landfills.

This paper combines the findings of two studies of recycled/waste fibers in dense graded asphalt concrete. One program was conducted in the laboratories of CTL/Thompson, Inc. in Denver, Colorado and the second comparative study was conducted at the University of Texas at Austin under the supervision of Dr. Thomas W. Kennedy. Laboratory investigations were conducted to measure the properties, performance, and effectiveness of the recycled fibers and commercially available fibers.

CTL/THOMPSON STUDY PROGRAM

The CTL/Thompson, Inc. laboratory investigation measured the mixture properties of a single asphalt cement-aggregate blend stabilized with four different fiber additives, two commercial fibers and two waste/recycled fibers. Questions addressed by this investigation about the use of fibers are:

* Is there a difference in performance between commercially available fibers and waste/recycled fibers?
* In a dense graded type mixture, is the void structure large enough to allow the fibers to be inert within the mix or do the fibers act as an aggregate?
* Does increased asphalt cement content imply improved durability?

Results of this research are intended to provide preliminary comparison between commercially available fibers and waste/recycled fibers, quantifying their laboratory mixture properties. To provide true comparisons between the fibers, the aggregate source, aggregate gradation and base asphalt cement remained constant throughout the study.

FIBERS

This investigation selected four fibers from locally available sources for comparison testing. Two commercially man-made fibers were selected from fibers presently available to the asphalt paving industry. Two waste/recycled fibers were selected from potential market sources. All of the fibers were added to the mixtures at a concentration of 0.3 percent by total weight of mix.

The two commercial fibers selected were cellulose and a polyester fiber. The cellulose was a cylindrical pellet composed of 50% cellulose fiber and 50% asphalt cement, by total weight. The fiber has an average length of 0.043 inches and a thickness of 0.002 inches. The polyester was a loose polyester fiber with an average length of 0.25 inches. The cellulose and polyester fibers are currently available to the asphalt paving industry.

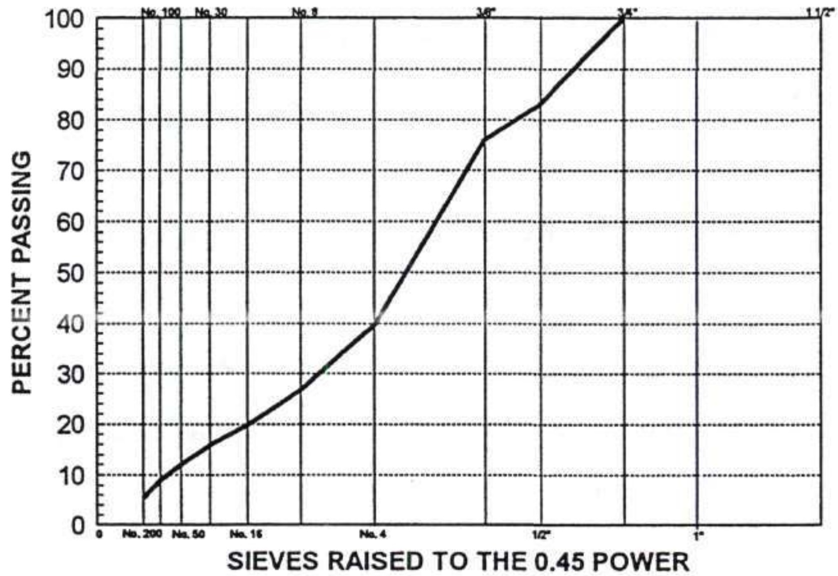
The two waste/recycled fibers selected were nylon, a processed waste fiber, and ground carpet fibers from processed carpet. The nylon fibers are a processed waste fiber from mills in Georgia and/or South Carolina. The Nylon 66 fiber stock has a mix denier of 2 to 6 and was cut into 0.25 inch lengths. The nylon waste fibers result from interruptions of spooling operations, with a yearly supply of 40 million pounds. The ground carpet fibers were cut from waste carpets. Carpet fiber lengths varied from a maximum length of 0.5 inches. The carpet backing was included in the cutting process. The carpet fibers are a recycled post-consumer fiber, ground to average fiber length. The yearly supply of the carpet fiber is up to 200 million pounds.

The waste nylon fibers are made as pure nylon strands, collected from interruption in the spooling operations, cleaned and cut to required length. The length and diameter of the waste nylon can be specified within range of commercial denier and desired length. The recycled carpet fibers are taken from homes and offices as waste carpet, ground with dust separation to average fiber length control.

MIXTURE MATERIALS

The asphalt-aggregate mixtures consisted of a graded crushed aggregate, a polymer modified asphalt cement, and the four fibers. The aggregates were crushed quarried rock from the Morrison quarry, a granitic deposit. The quarry, owned by Cooley Gravel Company, is located in Morrison, Colorado. Three aggregate products were blended to provide the design gradation. These included a 3/4 inch to No. 8 aggregate, a 1/2 inch to No. 8 aggregate and crusher fines which pass the 3/8 inch sieve. Figure 1 presents the design aggregate gradation plotted on the 0.45 power curve. This gradation is a dense graded mixture having a "voids in mineral aggregate" (VMA) of 12.7 percent.

Fig. 1 DESIGN AGGREGATE GRADATION



The base asphalt cement used in this research was an AC-10 asphalt cement, supplied by the Conoco Refinery in Denver, Colorado. The base asphalt cement was modified using a Styrene-Butadiene (SB) product, soluble in asphalt cement. The results of conventional asphalt cement tests conducted on this product are presented on Table I for both aged and unaged asphalt cement.

TABLE I - CONVENTIONAL ASPHALT CEMENT TESTS

BINDER TESTS	POLYMER MODIFIED AC-10	
	ORIGINAL	AGED
Viscosity @ 275° F, cSt	1160	2180
Viscosity @ 140° F, P	17600	60100
Penetration @ 77° F	68	49
Penetration @ 39.2° F	33	26
Softening Point, °F	148	159
Smoke Point, °F	300	285
Flash Point, °F	550	613
Solubility, %	99.6	99.6
Specific Gravity	1.02	1.02
Ductility, cm @ 77° F	49	26
Compatibility, °F	0	0
Loss on Heating, %		0.06

MIXTURE DESIGN

Five mix designs were performed, using the four selected fibers and one control mix without fibers. Viscosity was plotted according to ASTM D 2493 to determine the mixing and compaction temperature. Two hours of curing at the compaction temperature were allowed for asphalt cement absorption in the aggregate. Three 2.0 inch high samples were molded at each asphalt cement content using a gyratory compactor (ASTM D 4013). Stabilities were measured using the Hveem stabilometer according to ASTM D 1560. Air void (AV) and "voids in the mineral aggregate" (VMA) calculations were based on maximum theoretical specific gravity and aggregate bulk specific gravity. Optimum asphalt cement contents were selected at 4.0 percent air voids and ranged from 4.5 to 4.9 percent. Table II presents a summary of the conventional mix properties.

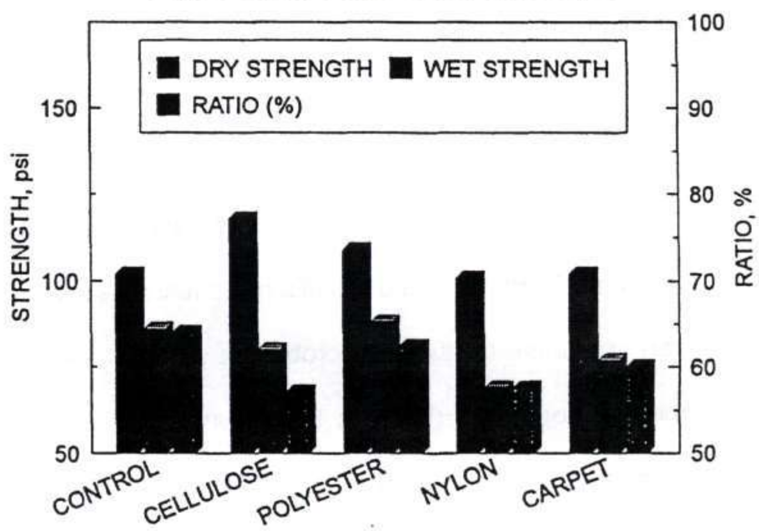
TABLE II - CONVENTIONAL MIXTURE PROPERTIES

Mixture Properties	Control	Cellulose	Polyester	Nylon	Ground Carpet
A.C. Content, %	4.5	4.8	4.8	4.8	4.9
Hveem Stability	45	38	38	40	41
Voids, %	4.0	4.0	4.0	4.0	3.9
VMA, %	12.7	13.1	13.3	13.8	13.4
Voids Filled, %	69	71	74	73	72
Compacted Density, pcf	151.2	150.8	150.4	149.6	150.4
Maximum Density, pcf	157.2	156.7	156.1	155.4	156.7

LABORATORY MIXTURE PERFORMANCE PROPERTIES

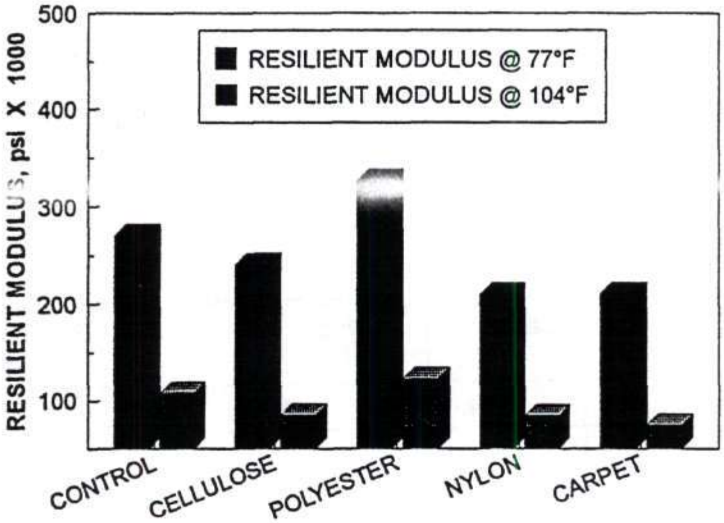
The Lottman test was used to indicate the durability characteristics of the fiber mixes. The method is an indirect tensile test where samples are moisture conditioned by vacuum saturation and a freeze-thaw cycle. Moisture susceptibility and durability is determined by the ratio of wet conditioned tensile strength to dry conditioned (as compacted) tensile strength. Research has correlated this procedure to approximately 10 to 15 natural freeze-thaw cycles. Specimens were made for each mixture at their respective optimum asphalt cement content. Samples were molded to 7 ± 1% air void level with the gyratory compactor. Figure 2 presents the results

Fig. 2 STRIPPING TEST RESULTS



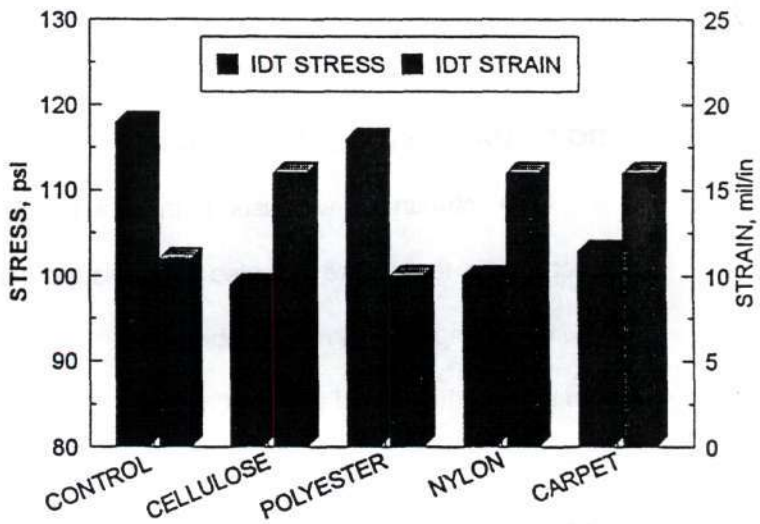
of these tests. Resilient Modulus (M_R)is a dynamic test response measured as the ratio of the repeated axial deviator stress to the recoverable axial strain of a material[2]. The test measures a material's response to repetitive loading and deformation. The Resilient Modulus of each mixture was determined at two temperatures (77°F, and 104°F) using samples compacted to 7 ± 0.5% voids with gyratory compaction. The data reported on Figure 3 were the average of three laboratory compacted samples of each mixture.

Fig. 3 RESILIENT MODULUS



The indirect tensile strain and indirect tensile stress at failure were also determined on the same set of mixture samples at 77°F test[3]. The same set of samples was measured for tensile stress and strain to compare strength conditions of the various fibers. These tests are related to performance using the NCHRP Asphalt-Aggregate Mixture Analysis System (AAMAS). Figure 4 presents the results of the indirect tensile tests for all mixtures.

Fig. 4 INDIRECT TENSILE TEST RESULTS

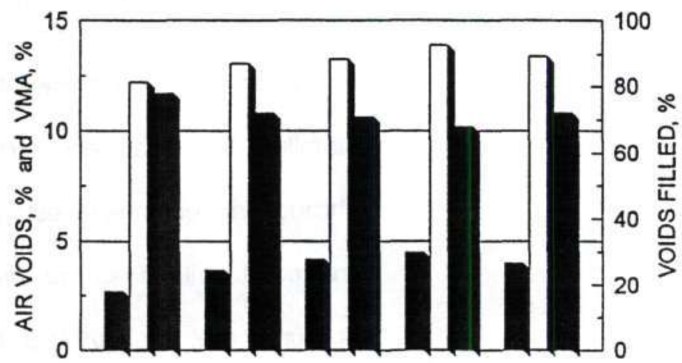


DISCUSSION OF RESULTS

The optimum asphalt contents were increased in all fiber mixes by as much as 0.3 to 0.4 percent. The total amount of voids also significantly affects the performance of a mixture. An inadequate amount of void space can contribute to durability problems; whereas, excessive void space can cause a loss in strength. Voids in mineral aggregate (VMA) is the volume of intergranular void space between the aggregate particles of a compacted mixture[2]. Fiber enhancement assumes that fibers act as a microscopic framework within the void structure that allows more asphalt cement to be held in the mixture. The waste/recycled fiber modified mixtures resulted in higher optimum asphalt cement contents and slightly higher VMA and voids filled. Theoretically, the VMA of the control mix and the fiber mixes should be equal; only the percentage of voids filled would increase due to the result of fiber addition and increased asphalt cement. The VMA results indicate a small increase in the VMA of the fiber mixes, as shown in Figure 5. The increase in VMA may indicate that some of the fibers are acting as filler.

Assuming the aggregate structure is similar for all mixtures tested in this investigation, the percentage of voids filled should increase and the air voids should decrease with the addition of fibers. An effective asphalt cement content of 4.0% was used for a volumetric comparison of the mixtures. The effective asphalt cement content is the total asphalt content minus the quantity of asphalt cement lost by absorption into the aggregate[2].

Fig. 5 VOLUME RELATIONSHIPS



	CONTROL	CELLULOSE	POLYESTER	NYLON	CARPET
AIR VOIDS ■	2.7	3.7	4.2	4.5	4.0
VMA □	12.2	13.1	13.3	13.9	13.4
VOIDS FILLED ■	78.0	72.0	71.0	68.0	72.0

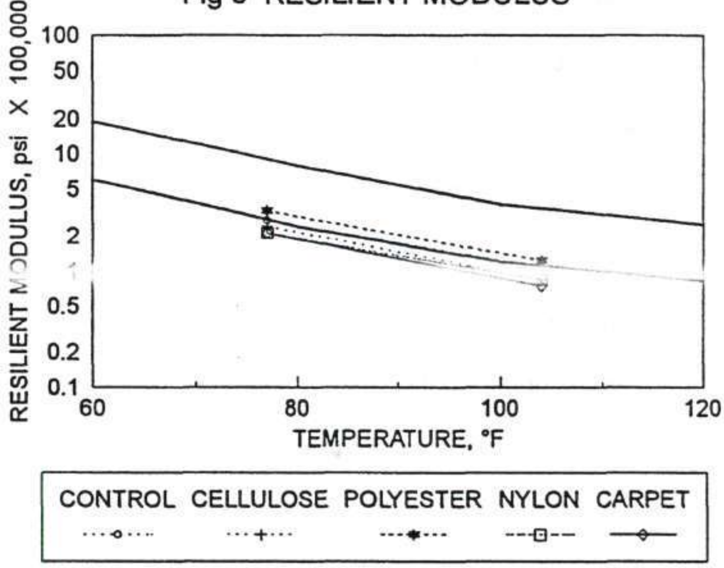
Results shown in Figure 5 suggests the air voids increased for the fiber enhanced mixtures and the voids filled decreased, implying that the same aggregate structure does not exist in the fiber mixes as compared to the control mix. The increased optimum asphalt cement contents of the fiber enhanced mixes does not reflect thicker films of asphalt cement; increased film thickness is exemplified by higher percent voids filled at the same VMA. Lower voids filled and higher VMA suggests that the aggregate matrix was displaced and additional asphalt cement is needed to coat the surface areas of the fibers.

Unlike a stone matrix asphalt where the aggregate gradation is gap-graded, the dense mixture is well-graded creating much smaller void spaces[1]. The void spaces in the dense graded mix are not large enough to allow all of the fibers to be inert.

The Lottman test results indicate that the polyester fiber has a higher retained tensile strength than the other fibers; however, none of the fiber mixes performed as well as the control mix. The waste nylon and ground carpet both had higher retained strength than the cellulose. The cellulose mixture exhibited a high dry tensile strength that may be related to the stiffer asphalt cement used to pelletize the fibers. Generally, fibers do not increase stripping resistance of mixtures.

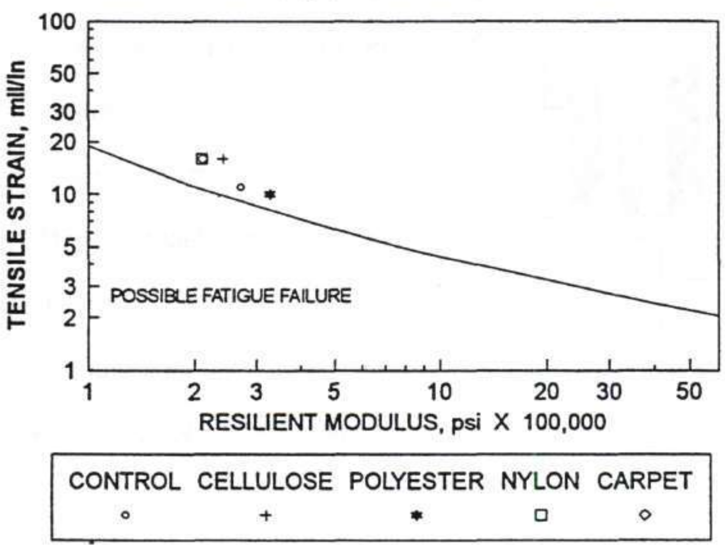
According to the AAMAS procedures, the Resilient Modulus should fall between the limits shown in Figure 6[3]. The polyester and control mixtures were the only mixes to meet this criteria.

Fig 6 RESILIENT MODULUS



All fibers, with the exception of polyester, did not decrease the tensile strain at failure or indicate early cracking problems through indirect tensile testing. Based on the indirect tensile strain at failure, all of the mixtures met the AAMAS requirements to resist fatigue cracking as shown in Figure 7. Tensile failures and thermal cracking are a function of the base asphalt cement. The increase in IDT strain at failure is beneficial for fatigue and thermal cracking resistance.

Fig 7 FATIGUE



UNIVERSITY OF TEXAS COMPARATIVE STUDY

A limited test program was conducted at the University of Texas at Austin to evaluate the effects of waste carpet fibers on the performance of asphalt mixtures. The study compared mixtures containing AC-20 and AC-20 with fibers. The performance related distresses evaluated were low temperature cracking, permanent deformation (rutting), and to a limited extent fatigue cracking.

EXPERIMENTAL DESIGN

The tests preformed on the two mixtures included indirect tensile test, repeated load indirect tensile test, Hveem stability test and Marshall stability test. The mixture properties estimated using these tests were:

* Indirect tensile strength at 77° and 39.2°F,
* Indirect modulus of elasticity at 77° and 39.2°F,
* Indirect resilient modulus at 77 and 39.2°F,
* Hveem stability at 140°F,
* Marshall stability at 140°F, and
* Marshall flow at 140°F.

All tests were conducted on Texas gyratory compacted specimens that were 4 inches in diameter and 2 inches high. The aggregates were rounded silicious river gravel (Eagle Lake) and a rounded field sand. The asphalt cement content was 4.6 percent by weight of the mixture. The 0.25-inch carpet fibers were introduced at a rate of 0.3 percent by weight of the mix. The indirect tensile tests were conducted at a deformation rate of 2"/min. at 77°F and 0.05"/min at 39.2°F. The resilient modulus tests were conducted using a haversine load pulse with a load duration of 0.2 seconds, a 0.8 second rest period and a resulting frequency of 1 cycle per second (ASTM D 4123).

The Hveem stability and the Marshall stability and flow were estimated and evaluated because these parameters are currently specified by most states although they have little if any relationship to performance. The other properties are more directly related to performance.

DESIRED PROPERTIES

Generally, to reduce permanent deformation it would be desirable to have high tensile strengths, indirect and resilient moduli at the higher testing temperatures. Low values of accumulated deformations would be desirable with high Marshall and Hveem stabilities and probably low Marshall flow values.

To reduce low temperature cracking the tensile strength should be high at lower testing temperatures, unless stiffness also increases. A low indirect and resilient moduli would be desirable for reduction of low temperature cracking. Probably higher Marshall flow values with lower Marshall and Hveem stabilities will improve low temperatures cracking properties. Reduced fatigue cracking in thin pavements would require high tensile strengths unless at temperatures below 77°F and if stiffness also increases. Fatigue cracking would also be reduced by low indirect and resilient moduli at testing temperatures below 77°F. Probable higher Marshall flow values and lower Marshall and Hveem stabilities would improve resistance to fatigue cracking.

RESULTS

The property tests were used to measure the expected performance of the AC-20 mixture and the AC-20 mixture with fibers. The tensile strengths of the mixtures containing AC-20 with fibers were greater than the tensile strengths of the mixtures containing only AC-20. At 39.2°F, however, the difference was not significant and for all practical purposes the strengths were equal.

Fig. 8 INDIRECT TENSILE STRENGTH RESULTS

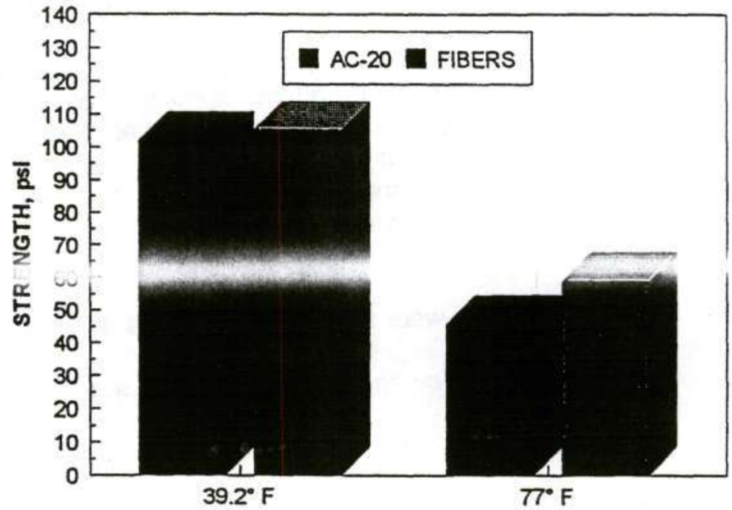
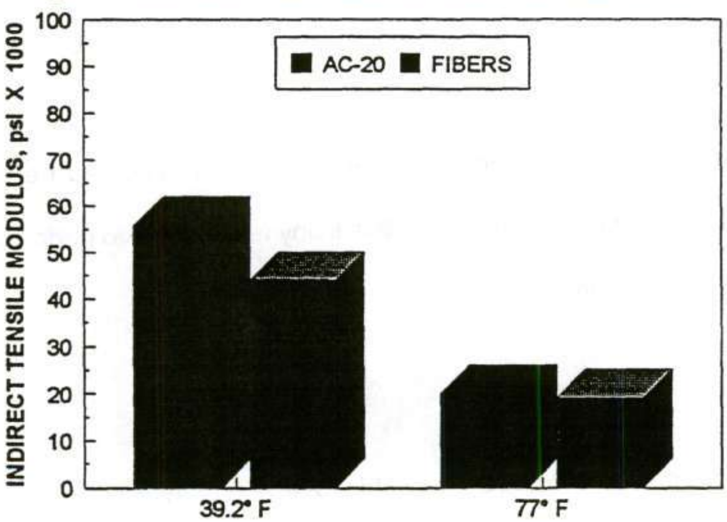


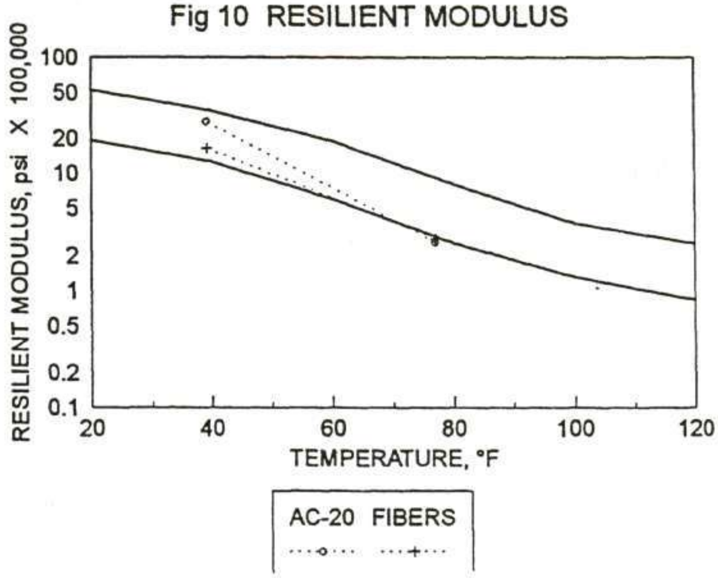
Fig. 9 INDIRECT TENSILE MODULUS OF ELASTICITY



The indirect tensile moduli (stiffness) were less for the fiber mixtures as compar to the mixtures without fibers. At 77°F, however, the differences were very small and for all practical purposes the mixtures exhibited equal stiffness.

The indirect tensile resilient modulus (stiffness) was less for the fiber mixtures as compared to the mixtures without fibers. But as with the indirect tensile modulus there was no significant difference at 77°F.

Fig 10 RESILIENT MODULUS



The Hveem and Marshall stabilities were greater for the fiber mixtures as compared to the mixtures containing AC-20 without fibers. The Marshall flow values were greater for the fiber mixtures.

Fig. 11 MARSHALL PROPERTIES

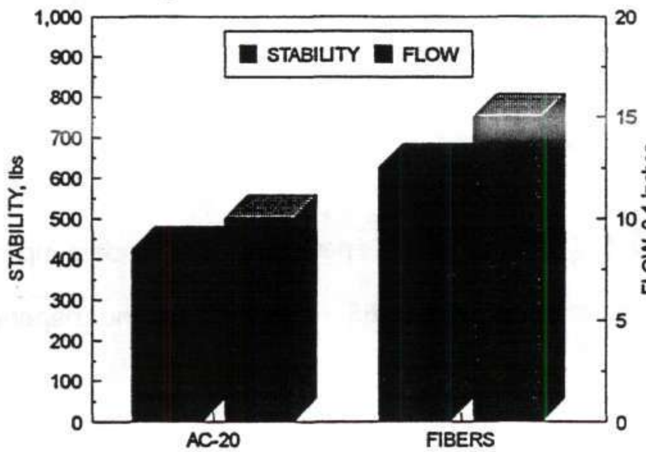
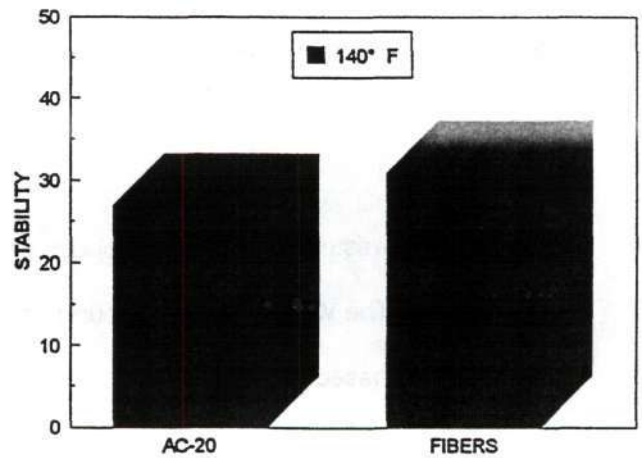


Fig. 12 HVEEM STABILITY



POTENTIAL EFFECTS ON PERFORMANCE

The addition of fibers effects the performance of asphalt mixtures according to results of the performance testing. The addition of fibers could reduce permanent deformation because of the higher tensile strengths and higher stabilities. Low temperature cracking could also be reduced by the addition of fibers because of the reduced stiffnesses (moduli) at 39.2°F and the increase flow value. For the same reasons the fatigue cracking for thin pavements can be reduced by adding fibers to the mixture.

PLACEMENT OF WASTE/RECYCLED FIBERS INTO MIXTURE

The waste/recycled nylon fibers may be added into batch plants by using pre-weighed bagged quantities, dumped into the pug mill. Proprietary mixing equipment has been developed to introduce fibers into a continuous mixing plant. The waste/recycled carpet fibers are processed into a baled material that is handled through proprietary mixing equipment with dust control. The mixing equipment is mobile and can be relocated to any continuous plant. Conventional paving equipment can be used in paving operations for fiber modified mixtures.

HEALTH AND ENVIRONMENTAL ASPECTS RELATING TO AIR QUALITY

The waste/recycled nylon fibers do not present an adverse health or environmental aspects duri..g handling. The fiber has no adverse leaching effects and is non-toxic to aquatic and terrestrial organisms. The ground carpet fibers, if handled with suitable dust masks, present no adverse health or environmental aspects. Dust control of the recycled carpet fibers is required for air quality. The ground carpet has no adverse leaching effects and is non-toxic to aquatic and terrestrial organisms.

COSTS

The waste/recycled nylon fibers are sold at $0.65 to $0.90 per pound, dependent upon quantity purchased. The waste/recycled ground carpet fibers are sold at $0.55 to $0.99 per pound, dependent upon quantity purchased.

CONCLUSIONS

Comparison of overall performance for the different fibers suggests a slight advantage for polyester fibe however, the variability of some test values are high and should be considered when analyzing this data. There was no significant deterioration in mixture performance due to the addition of fibers. The increased asphalt cement content does not reflect additional asphalt cement in the same mixture structure. The higher asphalt cement content is necessitated by the addition of fibers. Testing suggests the increased asphalt cement content does not increase the stripping resistance of the asphalt concrete. All fibers can be used in mixes with additional modifications to the mixtures, including gradation. The waste/recycled fibers performed as well as a commercially available fiber and in some tests performed better. The choice of which fiber to use should be separated by costs and environmental concerns. The waste/recycled fibers can be utilized in pavement construction, producing the same advantages as commercially available fibers and providing a use for the waste product.

Modifications to the aggregate gradation need to be made to allow room for fibers. An aggregate gradation that is gap-graded may show improved performance. Another modification may be to shorten the length of the fiber used; allowing the fiber to fit within the void spaces of the dense graded mixtures.

After review of the data presented, dynamic destructive testing of the fiber mixes may provide mo information on the effect different fibers have on dense graded asphalt concrete mixtures. According to laboratory test results and field observations, the waste/recycled fibers perform in asphalt concrete mixes as well as commercially available fibers at possibly a lower cost, while providing an environmentally safe way of disposing the waste fibers in a useful application in high performance pavement systems.

REFERENCES

1. Federal Highway Administration, "Stone Mastic Asphalt Surface Pavement Mixtures", Office of Technology Applications Engineering Application Division, Roadway Applications Branch, 1991.

2. Robert, Freddy L., P.S. Kandhal, E.R. Brown, D.Y. Lee, and T.W. Kennedy, Hot Mix Asphalt Materials, Mixture Design, and Construction, NAPA Education Foundation, 1991.

3. Von Quintus, H.L., J.A. Scherocman, C.S. Hughes, and T.W. Kennedy, "Asphalt-Aggregate Mixture Analysis System (AAMAS)", National Cooperative Highway Research Program Report 338, Transportation Research Board, March, 1991.

Bio-Sketch

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Mr. Gordon serves as the Project Manager for the Pavement Division of CTL/Thompson, Inc., a consulting geotechnical and materials engineering firm in Denver, Colorado. He is a registered engineer in Colorado. He graduated with a B.S. in Civil Engineering and a M.E. in Civil Engineering from Texas A&M University. He specialized in geotechnical and pavement engineering during his M.E. work. Mr. Gordon has experience with design and evaluation of all types of pavement projects. His experience includes applied research with asphalt additives and pavement construction, design of cargo roads and taxiways at Denver International Airport, design and evaluation of runways in Montana and Kansas and design of numerous city and subdivision streets. Mr. Gordon is leading CTL/Thompson's development and marketing of a pavement management program for municipalities, counties, and facilities, including evaluation and research of pavement performance.